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Highly Efficient On-Site Detection of Neutron Sources with the INT Measurement Car DeGeN

Wolfram Berky[1], Jeannette Glabian[1], Theo Köble[1], T. Lehmacher[2], Monika Risse[1]

[1]Fraunhofer Institute for Technological Trend Analysis (INT), 53879 Euskirchen, Germany
[2]Bundeswehr Research Institute for Protective Technologies and NBC Protection (WIS), 29633 Munster, Germany

Abstract—Counter-acting the potential misuse of nuclear and radioactive material has been a subject of tremendous importance for quite a while, and the detection of such material is a key figure to counter-acting measures in that respect. Especially regarding nuclear material, detecting gamma and neutron radiation simultaneously on-site with high efficiency provides a good chance of retrieving such material during transport after it was removed from nuclear facilities, either as a malicious act or simply by chance. The Fraunhofer INT's (Institute for Technological Trend Analysis) measurement car DeGeN (detection of gammas including neutrons) is equipped with highly sensitive ^{3}He neutron detectors and 12 l plastic detectors for gammas. After a reconfiguration of the measurement system, including new gamma detectors, the INT was given the opportunity of verifying the system's detection limits at the premises of WIS (Bundeswehr Research Institute for Protective Technologies and CBRN Protection) in Munster, Germany. Two different neutron sources were used for the experimental determination of the detection limits concerning neutrons. The results were then compared to theoretical detection limits which had been calculated previously. The results proved to be in good agreement overall.

Index Terms— Ionizing radiation sensors, gamma and neutron detection techniques, neutron detectors.

I. INTRODUCTION

Recently the Fraunhofer INT was provided with the opportunity to perform measurements with several neutron and gamma sources and the INT's measurement car DeGeN [1–3] at WIS (Bundeswehr Research Institute for Protective Technologies and CBRN Protection) premises in Munster, Germany. The DeGeN car (detection of gammas including neutrons) is equipped with ^{3}He tubes for neutron detection and with two 12 l NBR scintillation gamma detectors. However, we merely regarded the neutron measurements for the purpose of this study. The measurements aimed at determining the detection limits of the ^{3}He system regarding neutron sources depending on the sources' neutron emission rates and the car's velocity. Another aspect to be examined was the question whether the recent modification of the gamma measurement component (new and larger gamma detectors had been fitted) would affect the sensitivity of the system concerning neutron radiation as the gamma and neutron measuring components are located close to one another inside the car.

II. THE MEASUREMENT CAR DEGEN

The INT measurement car DeGeN based on a commercially available estate car is equipped with detectors for measuring both gammas and neutrons (see Figure 1). The neutron detectors are 6 Slab Counters by Canberra on either side of the vehicle which are filled with ^{3}He as detection material. Each of these detectors contains 6 tubes of 33 cm in length, 2.54 cm in diameter, and a ^{3}He pressure of $4.2 \cdot 10^5$ Pa. The tubes are surrounded by a layer of PE with a thickness of at least 1.7 cm for neutron moderation. The Slab Counters are connected in series, resulting in a summation of the detection volume which amounts to a very high sensitivity of the detection system.

Additionally, the system also comprises two 12 l NBR probes by Thermo for gamma detection. These are located near the rear side doors on the inside. The data measured by the gamma and neutron detectors are processed, transferred to a robust PC, and finally displayed on a touchscreen monitor by the corresponding measurement program. The monitor was positioned in the car's front and used by the person on the passenger seat to operate the measurement system. The power supply unit for the detection system can be seen at the car's center in Figure 1. The unit is connected to a battery providing a maximum charge of 130 Ah. The system can be operated self-sustained for up to 8 hours. While the engine is running, the battery is charged by the alternator. When the car is parked, mains supply provides the power. Figure 2 illustrates the arrangement of the neutron detectors as a schematic. The signals of all detectors on one side of the car are summarized, transferred to a neutron analyzer, and the corresponding data are then displayed on the PC.

The measured data are displayed on the monitor as waterfall diagrams (see Figure 3). The upper half of the diagram shows the values of the neutron signal rate, subdivided for the detectors on the left and on the right hand side. The bars move from top to bottom and are generally updated every two seconds. The same applies to the values of the gamma dose rate which are depicted on the lower half of the diagram, also separated for either side of the car. The interval of data refreshing is usually one second for the gamma component.

Corresponding author: Wolfram Berky (wolfram.berky@int.fraunhofer.de).

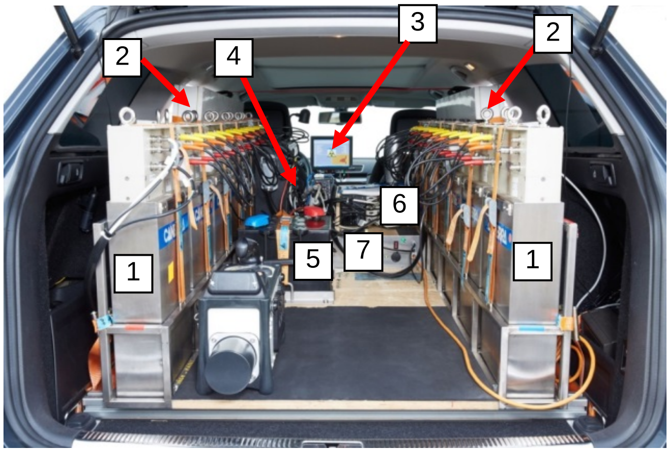


Figure 1. Rear view of the Fraunhofer INT's measuring car DeGeN with the system's components; 1: rows of ^{3}He neutron detectors; 2: plastic scintillator gamma detectors (12 l NBR); 3: touch screen monitor displaying gamma and neutron measurement values; 4: robust computer; 5: power distribution unit; 6: neutron analyzers; 7: power supply unit.

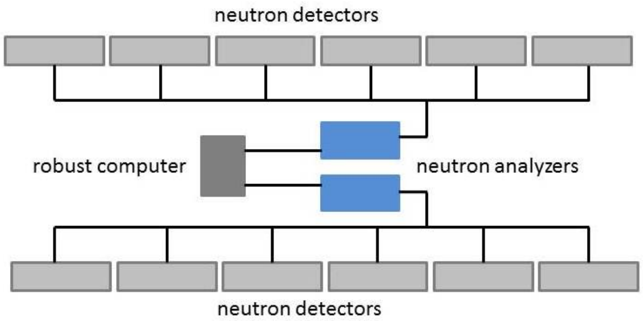


Figure 2. Schematic of DeGeN's neutron detection system: two rows of 6 detectors each whose signals are summarized, analyzed, and transferred to the computer.

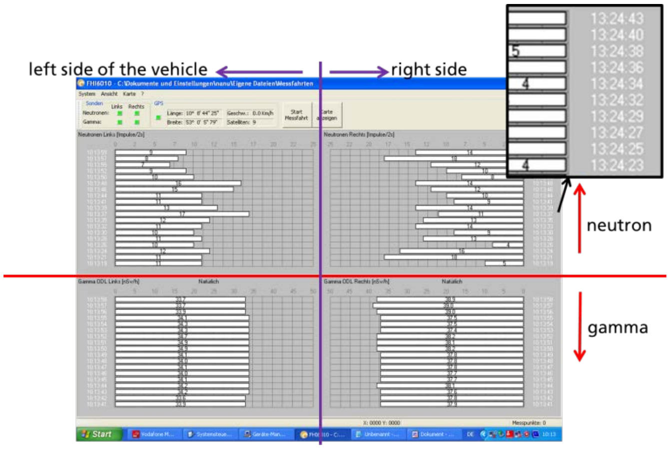


Figure 3. Desktop interface of the DeGeN measurement program with waterfall diagrams of the neutron signal rate (top) and gamma dose rate (bottom), separated for the left and right hand side of the car; the data run from top to bottom. In general the neutron data are updated every two seconds, the gamma data every second. The box at the upper right corner shows an enlarged section of the diagram, illustrating the lapse of the neutron measurement time.

III. WIS PREMISES

Figure 4 shows an aerial view of the premises, including the driving route as well as the positions of the radioactive sources between buildings 1 and 2. During the measurement drives, the car was turned on both ends of the route; a single measurement consisted of one round trip (back and forth). The driving velocities varied between 5 km/h and 60 km/h. The neutron radiation field was defined and varied by the distance between the positions of the sources and the driving route of 10 m up to 40 m. We also tested the effect of several moderation materials on the measurement results. Because of time restrictions we could not utilize all possible combinations of moderation materials. For the same reason, repetitions of measurement drives with the same parameters were not possible.

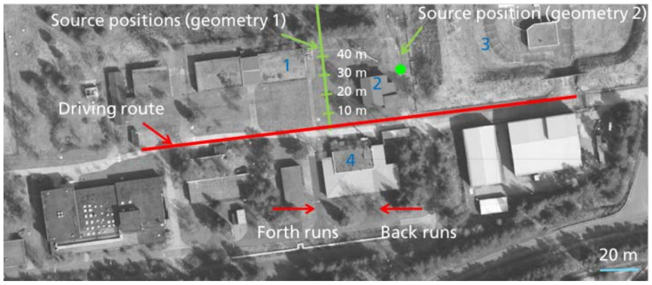


Figure 4. Aerial view of the part of the WIS premises relevant for the measurements. The driving route is marked in red, the sources' positions in green. The blue numbers refer to the surrounding buildings .

The sources were partly shielded by building no. 2, depending on the distance to the driving route. In the first geometry (geometry 1), the sources were positioned between buildings 1 and 2. Building no. 1 had a shielding effect merely for 40 m distance between source and driving route when the car was more than 60 m away from the source. The degree of the shielding effect caused by building no. 2 depended on the source's position: the further away from the driving route, the stronger the effect. Additional measurements were performed with the sources placed between building no. 2 and the site 3 on the WIS compound. This geometry (geometry 2) is also marked in Figure 4.

IV. RADIOACTIVE SOURCES AND MODERATION MATERIALS

Two different neutron sources were provided for the measurements: a ^{252}Cf source with a neutron emission rate of $1 \cdot 10^6$ n/s and an Am/Be source with an emission rate of $2.3 \cdot 10^6$ n/s, respectively. We used an explosive simulate as moderation material which comprises the chemical composition of a real explosive without actually being an explosive as well as a combination of this material and concrete. We also performed measurements without moderation material at all. The minimum distances between the car and the sources chosen in geometry 1 were: 10 m, 20 m, 30 m, and 40 m, the car's velocity values selected were: 5 km/h, 10 km/h, 20 km/h, 30 km/h, 40 km/h, 50 km/h, and 60 km/h for ^{252}Cf. In the case of Am/Be, we chose: 5 km/h, 20 km/h, 40 km/h, and 60 km/h. Because of time limits, the drives in geometry 2 were done at only one distance to the sources (30 m) and without moderation material. The corresponding velocities were for both neutron sources: 5 km/h, 20 km/h, 40 km/h, and 60 km/h.

Figure 5 shows an example of a measurement drive in a distance of 20 m. In order to maintain the correct distance to the source during the runs, a white line was drawn on the road, marking the required position of the left front wheel while running forth and of the right front wheel while running back, the latter being shown in Figure 5.

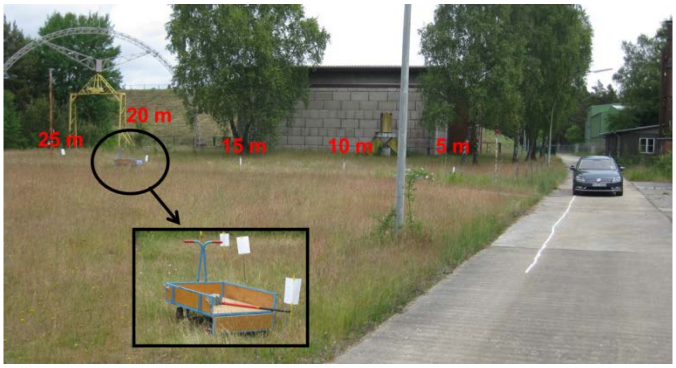
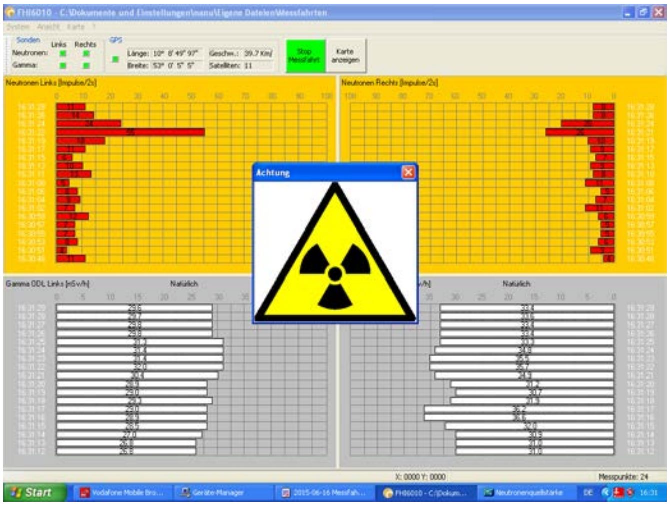


Figure 5. Typical setup for a measurement with a source at 20 m distance to the car; the white line simplified the correct positioning of the car relative to the source. The source was located on a cart at the black end of the (otherwise red) rod.

V. MEASUREMENT RESULTS

The display of the measurement program during a typical drive is shown in Figure 6 for the case of an Am/Be source shielded with 5 cm of explosive simulate and 10 cm concrete. The distance was 10 m; the velocity was 40 km/h.



Länge: 10° 8' 49" 97"
Breite: 53° 0' 5" 5"
Geschw.: 39.7 Km/
Satelliten: 11

Figure 6. Screenshot of the measurement program's desktop interface for a drive with the Am/Be source at 20 m distance to the car's left at 40 km/h. The source is shielded with 5 cm of explosive simulate and 10 cm concrete. The presence of the source was verified and an alarm was triggered; the direction of the source (on the left hand side of the car) is clearly recognizable.

The increase of the neutron signal rate is obvious; and one can clearly state that the source was on the car's left hand side as the detectors on this side generated a signal rate more than twice as high as on the other side. The source set off an alarm and was clearly seen and localized. In general 0-2 n/s can be taken into account as neutron background. For six neutron slab counters on one side and a measurement time window of 2 s this leads to an expected background measurement value of 0-24 counts/2s. The alarm in general is set within this range with regard to the measured background. The background on the experimental site was measured during a longer test-drive and was determined to an average of about 7 counts/2s but up to 19 counts/2s.; in order to minimize the false positive alarms the threshold for the neutron alarm was set to 20 counts/2s.

A. *Measurements with ^{252}Cf*

Overall the ^{252}Cf source positioned in geometry 1 without moderation material was recognized at all distances, only during the return drive with 40 km/h no alarm was set off. This can be ascribed to the aforementioned shielding effect of building no. 2. Up to a distance of 20 m the source was recognized for all velocities and types of moderator. Figure 7 shows a related extract of measurement data with a shielding of 5 cm explosive simulate and 10 cm concrete. In here the data obtained only with the slab counters on the side of the car which was closer to the source are given.

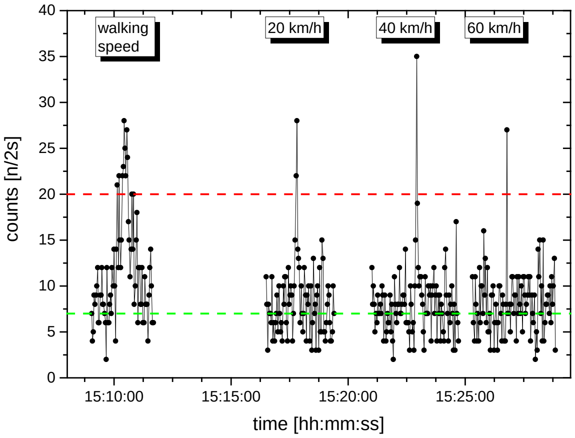


Figure 7: ^{252}Cf source, 5 cm explosive simulate and 10 cm concrete, measured while bypassing in 20 m distance with different velocities. Measurement data of the slab counters on the side of the car closer to the source for the stated velocities. Red dashed line: alarm threshold, dashed green line: average neutron background on WIS site.

The green dashed line represents the average neutron background on the WIS area. The value set for the alarm threshold at 20 n/2s is marked with the red dashed line. Data for walking speed up to 60 km/h are given. In all four cases, independent of the velocity, the alarm threshold is clearly exceeded and the source is detected.

At 30 m distance the source was recognized without moderator and with 5 cm explosive simulate, respectively. The results for 5 cm explosive simulate and 10 cm concrete are shown in Figure 8, analogue to Figure 7. In addition the times when passing the source are marked with a blue line. The data obtained during back drives merely show a reliable exceeding of the alarm threshold in the case of walking speed. For 20 km/h the source was passed two times, in the first case the threshold was exceeded, in the second it was not, but one can see a rise in the data at the position of the source. For 40 km/h the highest value is measured at the turning point of the route, not when passing the source. Therefore the detection limit in that case is determined as 30 m.

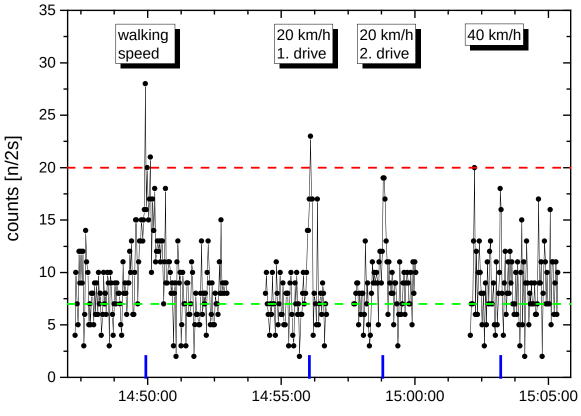


Figure 8: ^{252}Cf source, 5 cm explosive simulate and 10 cm concrete, measured while bypassing in 30 m distance with different velocities. Measurement data of the slab counters on the side of the car closer to the source for the stated velocities. Red dashed line: alarm threshold, dashed green line: average neutron background on WIS site. Blue marks indicating shortest distance of the detectors to the source.

At 40 m distance only measurements with an unmoderated source could be performed because of time limitations. As it turned out, the verification of the source's location did basically not depend on the velocity due to the measurement interval of 2 s. The source was localized in all cases except on the back run with 40 km/h which indicates the detection limit at 40 m. The verification of the source positioned in geometry 2 (between two buildings) was not successful in any case, although increased signal rates occurred in part. We conclude that the time frame during which the source was not subjected to the shielding effect of building no. 2 or the site 3 was too short.

B. Measurements with Am/Be

In geometry 1 the Am/Be source was recognized during all measurements with the exception of the drive at 60 km/h at 40 m distance with simulate and concrete moderation. Even in geometry 2 the source, whose neutron emission rate was more than twice as high compared to the ^{252}Cf source, could be recognized in part.

C. Detection Limits of DeGeN

The previously mentioned results allow for an approximate determination of the car's detection limits regarding both utilized neutron sources. Here the term detection limit is defined as the maximum distance between car and source where the source could still be detected by means of an alarm that was raised. This corresponds to the respective neutron emission of the source. Due to the fact that ^{252}Cf and the Am/Be source are not equivalent and differ in their energy spectra, the limits have been specified individually. The values are listed in Table 1, depending on the moderation material. Because of a higher neutron emission, the detection limits of the Am/Be source proved to be above those of the ^{252}Cf source.

Calculations regarding the neutron component of the DeGeN measurement system in order to evaluate the system's detection limits had been performed before [4]. The calculations are based on a well-known background count rate so that the uncertainty in the background can be neglected. Then the detection limit in terms of distance between source and detectors can be iteratively calculated. Here the detection limit was calculated at three standard deviations above background.

Table 1. Detection limits derived from the measurement results as well as gained by calculations, depending on distance for both neutron sources.

	Neutron Emission [n/s]	Detection Limit [m]				
		no moderation		5 cm simulate	5 cm simulate + 10 cm concrete	10 cm concrete
		derived from measurements	calculated	derived from measurements	derived from measurements	calculated
^{252}Cf	$1\cdot10^6$	40	35	≥ 30	30	30
Am/Be	$2.3\cdot10^6$	> 40	> 40	> 40	≥ 40	≥ 40

The calculated values of the detection limit proved to be in good correspondence with the experimentally determined values, both are shown in Table 1. Since the calculations were performed with a moderation of only 10 cm and 20 cm of concrete, we compared the results of the source moderated with 5 cm of simulate and 10 cm of concrete with calculations with 10 cm of concrete.

VI. CONCLUSIONS

To conclude the DeGeN measurements one can state that, given the constraints of time, systematic and quite thorough experiments could be performed. The high efficiency of the ^{3}He neutron counters was demonstrated and confirmed once again [3], and it was shown that in the lapse of years past no loss in performance has occurred. The results of the experimentally determined detection limits of the measurement system regarding neutron detection agreed well with previously calculated values.

ACKNOWLEDGMENT

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VII. REFERENCES

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